Report for 2002NJ5B: Destruction of Volatile Organic Compounds Using the Photo-Chemical Remediation Reactor

- Conference Proceedings:
    - Lee, K. Y., J. J-Y. Lee, and J. R. Stencel, 2002, Destruction of vapor-phase tetrachloroethylene (PCE) and trichloroethylene (TCE) using a novel photo-chemical remediation reactor, Partners in Environmental Technology Technical Symposium & Workshop, SERDP/ESTCP, 13, Washington DC.
    - Lee, J. J-Y., K. Y. Lee, and J. R. Stencel, 2002, Destruction of vapor-phase PCE using a novel photo-chemical remediation reactor, Thirty-Fourth Mid-Atlantic Industrial and Hazardous Waste Conference, edited by M. M. Häggblom, D. E. Fennell, and K. Y. Lee, 137, New Brunswick, NJ.
- Articles in Refereed Scientific Journals:
    - Lee, K. Y., 2003, Transport of contaminants resulting from dissolution of a coal tar pool in saturated porous media, submitted, Environmental Science & Technology.
    - Lee, K. Y., J. J-Y. Lee, J. Khinast, J. R. Stencel, and M. Lavid, 2003, Photo-chemical remediation of PCE: Reactor design, construction, and preliminary results, in press, Journal of Environmental Engineering, ASCE.
- Dissertations:
    - Lee, J. J-Y., Photo-chemical remediation of volatile organic compounds, Ph.D. dissertation, Civil and Environmental Engineering, Rutgers University, in progress.
- unclassified:
    - Lee, K. Y., K. Kostarelos, and D. E. Fennell, 2003, Modeling the transport of dissolved contaminants originating from a NAPL source containing PAH compounds in groundwater, submitted, Water Research.

Report Follows:

Project Information:

A custom designed pilot-scale Photo-Chemical Remediation reactor is constructed for remediation of vapor-phase volatile organic halocarbons (VOHs), particularly chlorinated hydrocarbons such as PCE (tetrachloroethylene). Ultraviolet (UV) light, when emitted at an effective absorption frequency, cleaves a VOH's carbon-chloride bond, transforming harmful contaminants to harmless products. The stainless steel reactor is of tubular-shape with an inner diameter of 32 cm and a length of 105 cm. The net volume of the reactor is approximately 73.7 liters. Three stainless steel baffles are welded inside the reactor to create a well-mixed vapor phase and uniform UV contact time. Special low-pressure mercury amalgam UV lamps (Heraeus Inc.) are used as the photo energy source. Two independent vapor-phase PCE destruction experiments are conducted using different influent contaminant concentrations. Both experiments show a PCE destruction efficiency of over 99%.

Methodology

Figure 1 shows a schematic diagram of the reactor and the vapor phase flow path. Stainless steel (type 304) is selected for the construction of the tubular reactor vessel because of cost considerations, ability to resist corrosion, and ease in fabrication. The reactor is insulated to minimize heat loss. The reactor has an inner diameter of 32 cm and a length of 105 cm. The reactor volume is approximately 84.1 liters and this volume is reduced to approximately 73.7 liters with the insertion of sixteen Suprasil glass sleeves and three internal baffles. The Suprasil glass sleeves are geometrically positioned to provide uniform UV exposure inside the reactor (see Figure 1). Each Suprasil glass sleeve holds a low-pressure mercury amalgam UV lamp (Heraeus Inc.), which protects the UV lamp from contaminant vapor while allowing transmission of UV light into the reactor. Each UV lamp has an input power of 200 watts and an UV output of approximately 60 watts (30%). The internal baffles within the reactor help to provide a well-mixed flow of gas through the reactor and homogeneous UV contact time. Three thermocouples are mounted on the reactor to observe reactor temperature progression. The reactor and all associated hardware are mounted on a mobile frame for possible technology demonstration at a field site.

Table 1. Experimental Conditions

	Air compressor 2 flowrate [L/min]	PCE bubbler flowrate [L/min]	Reactor inlet PCE conc. [ppm_v]	Reactor residence time [min]
Experiment 1	4.36	0.19	94.0	16.2
Experiment 2	8.65	0.19	58.3	8.3

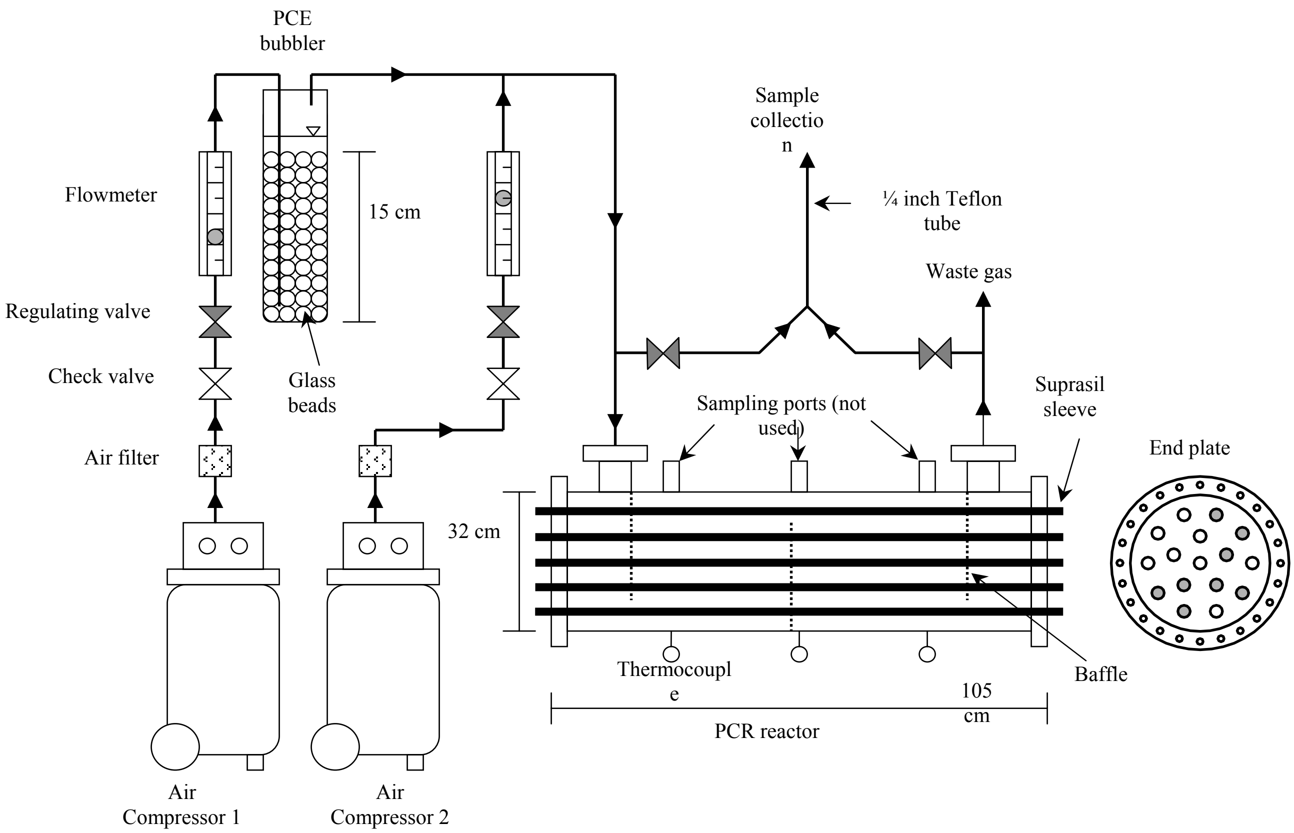

Figure 1: Reactor Flow Path.

Principal Findings and Significance

Two vapor-phase PCE destruction experiments are conducted in this study. The experimental conditions for each experiment are shown in Table 1. The main difference between the two experiments is the airflow rate from the second air compressor, which changes the vapor-phase PCE concentration into the reactor and also the reactor residence time. Prior to turning on the UV lamps, samples are collected and analyzed from the reactor inlet and outlet ports to verify consistent initial vapor-phase PCE concentrations throughout the reactor. Next, the UV lamps are turned on and effluent samples are collected and analyzed from the outlet port as a function of time. The effluent vapor-phase PCE concentrations as a function of time for both experiments are plotted in Figure 2. It should be noted that for each experiment the UV lamps are turned on at $t = 0$ min and are turned off at $t = 49$ min for the first experiment (solid circles) and $t = 56$ min for the second experiment (open circles). It should also be noted that only 8 UV lamps are operative during the experiments, and the operative lamps and their respective position within the reactor are shown on the end plate as shaded circles in Figure 1. It is apparent that the upper left corner of the reactor is without operative UV lamps. However, the UV/PCE contact time is assumed uniform due to the internal baffles. Results from both experiments showed PCE destruction efficiencies over 99%. It should be noted that in this preliminary study we are mainly interested only in the destruction of PCE. Hence, no end-products were analyzed.

Temperature could be a major factor affecting the photo-chemical reactions. Elevated temperature may increase the strength and rate of UV light absorption, and also broaden the range of light absorption, which leads to absorption shift to a longer wavelength. In this study, the reactor temperature reached in excess of 140°C due to heat generated from the UV lamps. To check for thermal destruction of PCE, an effluent sample is collected and analyzed for each experiment after the UV lamps are shut off. Note that for each experiment the effluent vapor-phase PCE concentration returned to the initial PCE concentration (see Figure 2) indicating no thermal destruction of PCE.

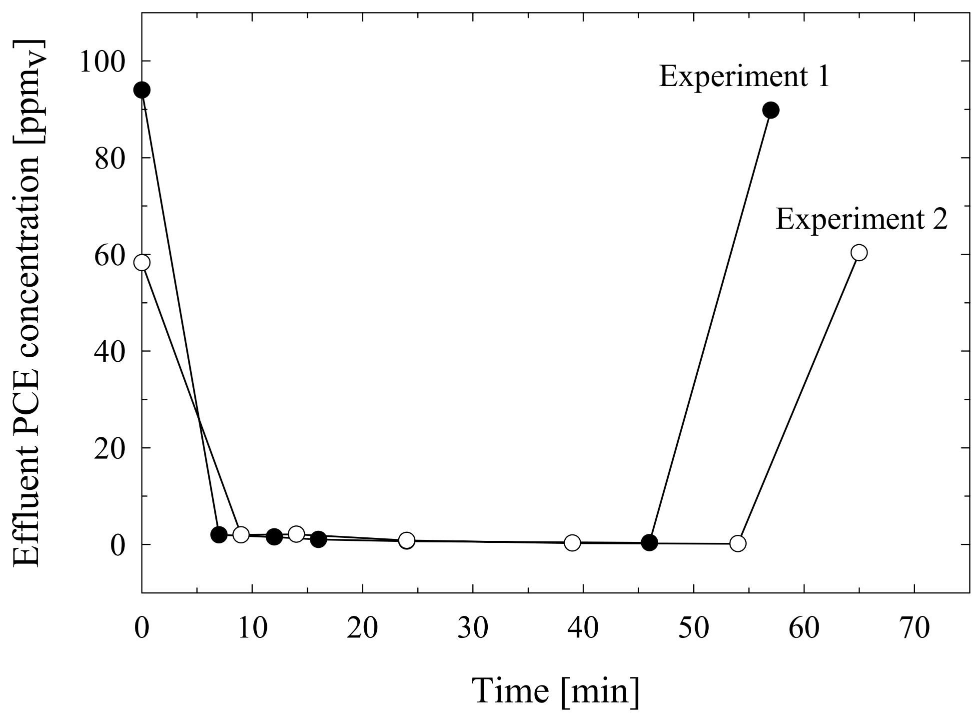

Figure 2: Effluent vapor-phase PCE concentrations as a function of time for experiment 1 (solid circles) and experiment 2 (open circles). The eight UV lamps are turned on at t=0 min for both experiments and are shut off at t=49 min for experiment 1 and at t=56 min for experiment 2.

Summary

A novel pilot-scale photo-chemical remediation reactor was designed, constructed, and utilized to perform two preliminary vapor-phase PCE destruction experiments. Influent vapor-phase PCE concentrations of 94.0 and 58.3 ppm_v with respective reactor residence times of 16.2 and 8.3 minutes were considered. The results show PCE removal efficiency of over 99% for both experiments. Furthermore, no thermal destruction of PCE was observed near 140 °C. The results from this study are very encouraging, and pave the way for future chlorinated hydrocarbon destruction experiments using other widespread contaminants such as TCE and TCA (trichloroethane).